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Precision Livestock Farming Technologies in Beef Cattle Production: Current and Future

Oranuch Wongpiyabovorn, Tong Wang, Hector Menendez, and Airish Lou Yago

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In the modern beef industry, beef cattle farming has evolved towards larger and fewer operations. During the past decade (2012–2022), the number of beef cattle operations in the United States decreased by 14.6%, while the number of beef cows increased by 5.9% (USDA NASS, 2012, 2022). Notably, the number of beef cattle operations with 500 or more beef cows increased by 27.0% in 2022.

As beef cattle operations continue to expand in scale, providing individualized care has become more challenging. The traditional reliance on observational skills and hands-on experience from beef cattle farmers is no longer sufficient to effectively manage the large cattle herds (Parsons et al., 2007). Moreover, the intensification of cattle production has caused potential environmental impacts, including climate change, groundwater pollution, and air quality issues, as well as concerns about animal welfare (Buller et al., 2020). Thus, managing large herds with a decreasing number of farmers presents significant challenges in the modern beef cattle industry, highlighting the need for solutions.

In response to this challenge, Precision Livestock Farming (PLF) has emerged as a potential solution. Over the past two decades, advancements in information and communication technologies, the Internet of Things, wireless communication networks, and improved internet accessibility significantly contributed to the PLF development (Terrasson et al., 2017). For example, PLF has evolved from simple animal identification to comprehensive systems with innovative wearable sensor monitoring an animal's health condition and behavior (Halachmi et al., 2019). These PLF systems operate automatically, providing a constant stream of information that allows farmers to closely observe, monitor, and analyze the health and performance of their cattle. These advancements have revolutionized the way farmers monitor and manage their livestock. The application of PLF technologies in the livestock industry has huge potential to improve animal health and welfare, reduce on-farm labor and veterinary costs, improve farm waste management, and promote environmental and economic sustainability in the long run (Tzanidakis et al., 2023).

While extensive research has explored the adoption of precision agriculture in crop production, the literature on PLF remains limited, primarily focusing on dairy cattle (Bianchi et al., 2022). To date, no existing study has specifically compared the adoption rates of various PLF technologies for grazing livestock. The main objectives of this study are to (i) explore the current awareness and adoption status of PLF technologies and (ii) identify the focus technologies that producers would be interested in adopting.

Precision Grazing Management Technologies and their Potential Benefits

Livestock Movement Tracking and Controlling

PLF technologies have shown greater potential in cattle grazing management. For the past two decades, a combination of virtual fencing and GPS-enabled collars has become commercially available (Tzanidakis et al., 2023), which allowed producers to control livestock grazing without physical fences. When cattle approach the designated boundary, the collars emit audible cues, and if they continue to cross, they receive a harmless electric shock (Campbell, 2020). This innovative approach supports rotational grazing and comes with multiple advantages, including reduced labor costs, adaptability to challenging terrains, exclusion of cattle from hazardous zones and wildlife habitats, and prevention of overgrazing (Campbell, 2020). In addition, animal location tracking technologies help prevent livestock theft and monitor the well-being of the animals (Aquilani et al., 2022; Tzanidakis et al., 2023).

Animal Health and Performance Monitoring

In recent years, PLF technologies have increasingly been utilized for animal health tracking, breeding monitoring, and performance monitoring (Murphy et al., 2021). Animal health monitoring technologies utilize various sensors, including accelerometers and GPS tracking, to collect data on parameters such as body temperature, heart rate, feeding behavior, and location (Neethirajan, 2017; Bailey et al., 2018). Such innovations can help detect potential diseases, health disorders, breeding abnormalities, heat stress, and hypothermia. Breeding monitoring technologies are essential for preserving genetic potential and reproductive health by optimizing breeding timing, reducing calving intervals, and improving breeding success rates (Neethirajan, 2017). Innovations in daily precision weighing systems, such as walk-over weighing (WoW) platforms, enable farmers to closely monitor animal performance, growth, and body weight gain, providing valuable insights for efficient and effective herd management (Segerkvist et al., 2020).

Feed and Water Management

PLF technologies related to forage management, such as precision monitoring of forage quality and quantity, forage species composition, and soil moisture, help farmers estimate forage availability and nutritive value and adjust stocking rates (Bretas et al., 2024). This information about forage intake supports precision feeding, which optimizes feed supplementation and ensures a balanced diet for livestock. In addition, daily water monitoring provides information on animal water intake, which facilitates effective management of water usage and ensures water availability (Bailey et al., 2018; Williams et al., 2020).

Environmental Impact Monitoring

PLF technologies also contribute to reducing environmental impacts by tracking animal greenhouse gas (GHG) emissions. These technologies employ sensors to monitor and measure methane concentrations in animal-living areas, which can differ based on factors like feed composition and quantity, animal species, manure management, and climate conditions (Borhan and Khanaum, 2022). The data obtained from these sensors facilitate strategies to reduce animal emissions, including dietary adjustments and implementing effective manure management practices, to promote sustainable livestock farming practices (Borhan and Khanaum, 2022).

Survey and Data Description

We conducted a survey of agricultural producers in three states (North Dakota, South Dakota, and Texas) during the first quarter of 2022. This is a re-survey of the 870 respondents who had previously completed our 2018 survey (Wang et al., 2020; 2022). The initial sampling criterion was that farm operations needed to have at least 100 non-feedlot cattle. In addition, we excluded counties in the western part of North and South Dakotas due to substantial public lands, which could potentially influence producers' management strategies. Our survey area in Texas covers counties where rangeland is the dominant land use type, namely Panhandle, Rolling Plains, and Central and West Central regions. A modified Tailored Design Method was followed for the survey process. The survey participants were contacted up to four times. First, an advance letter was sent explaining the project and providing the link to the online questionnaire. Second, a paper questionnaire was mailed along with a stamped return envelope. This was followed by a reminder/thank you postcard after two weeks and, for those who did not respond, a second paper questionnaire.

Out of 781 eligible samples, 54 producers no longer had cattle operations, and 35 mailing addresses were undeliverable. Ultimately, we received a total of 334 responses, resulting in a response rate of 42.8%. North and South Dakota farmers accounted for 66.1% of respondents, and the rest were located in Texas. The average age of respondents was 67.5 years old (median = 69), with 38.9 years of farming experience (median = 40 years). While the average producers' age is higher than the Census average (54.6 years in North Dakota, 60.5 years in South Dakota, and 53.2 years in Texas) (USDA NASS, 2022), this corresponds with a larger average farm size among our survey respondents (3,875 acres: grazing lands = 2,814 and cropland = 1,061), compared to the average beef cattle farm sizes of 672 (Texas) – 2,368 (South Dakota) acres from 2022 Census.

The questionnaire assessed the awareness and adoption status of 12 PLF technologies under four categories: (i) location control (virtual fencing and animal location tracking); (ii) performance check (animal health tracking, breeding monitoring, and performance monitoring); (iii) forage and water management (daily water monitoring, precision mineral supplementation, precision forage supplementation, monitoring of forage quality and quantity, monitoring of forage species composition, and precision monitoring of soil moisture); and (iv) environment (GHG emissions monitoring). For each technology, respondents could select between "Adopted" and "Not adopted yet." For those who have not adopted yet, three options were provided to gauge their awareness and potential for future adoption: "Not aware," "Aware but will not adopt," and "Aware and may consider adoption." To gauge the future adoption potential of PLF technologies, we calculated an adoption likelihood index using the number of farmers who may consider adoption divided by the number of those who will not adopt. The higher the index, the more likely the corresponding technology will be adopted in the future.

In addition, participants were asked about the challenges affecting their decision to adopt precision grazing technologies. Due to the nature of precision technologies, these innovations are mostly complicated and require initial investments, the use of the internet, and extra time to learn them. We listed five potential challenges in our survey: high cost, too time-consuming to learn, lack of information/demonstration, lack of reliable internet connection, and data security concerns. Respondents had the option to specify other challenges as well. For each listed challenge, five options were provided: “Not a Challenge,” “Minor Challenge,” “Some Challenge,” “Quite a Challenge,” and “Great Challenge.”

PLF Technology Adoption Status

Our survey data shows that the adoption rates of PLF technologies range from 0.7% to 18.8% (see Table 1). Of the 12 listed PLF technologies, only four had adoption rates of more than 10%, suggesting a long way to go before PLF technologies gain wide acceptance by the ranchers. The low adoption rates for these technologies were also observed in a recent Agricultural Resource Management Survey, which shows that wearable livestock technologies were adopted by 1% of small farms and 12% of large farms in the U.S. (Lim et al., 2024). These results suggest relatively low adoption of precision grazing technologies compared to those used in crop production. For instance, Wang, Jin, and Sieverding (2023) found that 86.1% of row crop farmers adopted at least one precision technology, while Lim et al. (2024) showed that the adoption rates of yield monitoring, guidance autosteering, and variable rate technologies ranged between 32% and 70% among midsize to large-scale farms.

When comparing across categories, we found that the adoption rates are highest for PLF technologies under the feed management category, with precision mineral supplementation leading at 18.8%, followed distantly by daily water monitoring and monitoring of forage quality and quantity, both at 11.8%. PLF innovations for monitoring livestock health and performance are the second most adopted category, with adoption rates ranging from 3.0% for performance monitoring (precision weighing) to 8.9% for breeding monitoring. In contrast, the adoption rates of technologies used for location control, virtual fencing and animal location tracking, were only 3.6% and 3.3%, respectively. Technologies for animal GHG emission monitoring had the lowest adoption rate at 0.7%, indicating less focus on technology addressing environmental and climate change concerns.

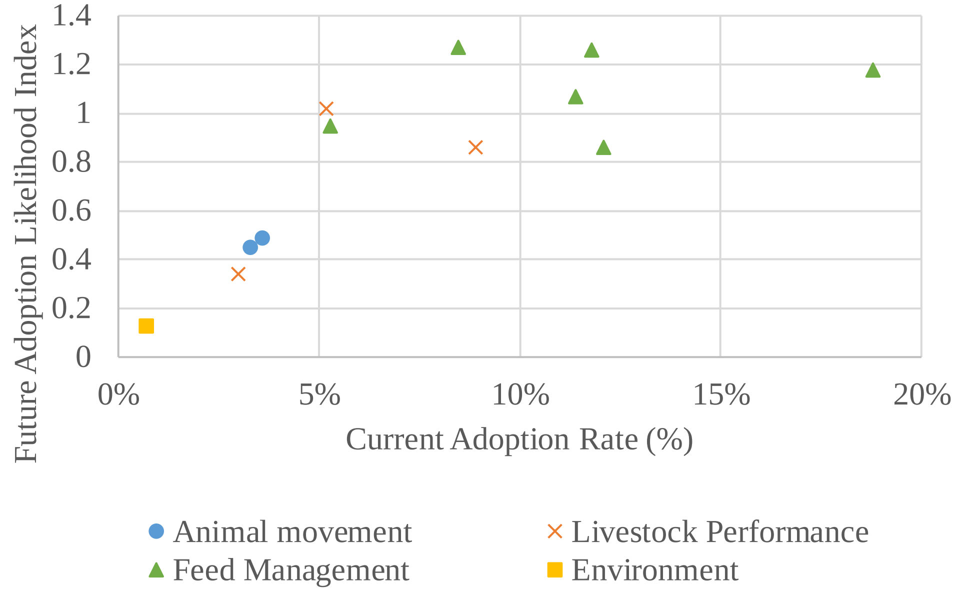
The differences in adoption rates across categories suggest livestock producers generally prefer to adopt some technologies over others. The top four most adopted PLF technologies all belong to the feed

Table 1. Awareness and Adoption Status of Precision Livestock Farming Technologies

Categories	Precision Grazing Technologies	Adopters	Non-Adopters			Potential for Future Adoption	
			Not aware	Aware but will not adopt	Aware and may consider adoption	Index	Ranking
Animal Movement	Virtual fencing	3.6%	38.9%	38.6%	19.0 %	0.49	9
	Animal location tracking	3.3%	28.1%	47.2%	21.5%	0.45	10
Livestock Performance	Animal health tracking	5.2%	29.4%	32.4%	33.0%	1.02	5
	Animal breeding monitoring	8.9%	27.9%	34.1%	29.2%	0.86	8
	Animal performance monitoring	3.0%	30.0%	49.8%	17.2%	0.34	11
Feed Management	Daily water monitoring	12.1%	29.6%	31.3%	27.0%	0.86	7
	Precision mineral supplementation	18.8%	29.6%	23.7%	27.9%	1.18	3
	Precision forage supplementation	11.4%	32.6%	27.0%	29.0%	1.07	4
	Precision monitoring of forage quality and quantity	11.8%	31.8%	24.9%	31.5%	1.26	2
	Precision monitoring of forage species composition	8.5%	36.0%	24.5%	31.1%	1.27	1
	Precision monitoring of soil moisture	5.3%	30.8%	25.0%	30.9%	0.95	6
Environment	Animal greenhouse gas emissions monitoring	0.7%	40.4%	52.3%	6.6%	0.13	12

Note. Adopters and non-adopters of each technology are shown as a percentage of total respondents. The index of the potential for future adoption is calculated from the number of respondents who are aware of the technology and may consider adoption divided by the number of respondents who are aware of the technology and will not adopt it, while the ranking shows the relative potential adoption across precision grazing technologies.

Figure 1. Relationship Between Current Adoption Rates and Future Adoption Likelihood Indices



Source: Authors' calculations.

management category, implying that livestock producers tend to perceive a positive correlation between PLF adoption in feed management and boosted livestock performance. Consequently, the latter leads to increased productivity and profitability.

Compared to adoption rates, awareness rates are much higher and have lower variance. Roughly two-thirds of the producers have been aware of the listed technologies, ranging from 59.6% in GHG emission monitoring to 72.2% in animal breeding monitoring. These results indicate that while the adoption rates remain low, most livestock producers have heard about PLF technologies.

Figure 1 shows that the future adoption trends of PLF technology can be reflected in the adoption likelihood indices, which, to a large degree, mirror the current adoption rates. The top four adoption likelihood indices, which are greater than one, all fall again under the feed and grass management category. A greater-than-one index indicates that more respondents are interested in adopting these technologies than those who do not plan to adopt them. Among these innovations for monitoring livestock health and performance, animal health tracking technology had the most interest, with the adoption likelihood index higher than one. Although virtual fencing was first used to control livestock in 1987, the interest in virtual fencing ranked ninth among the 12 PLF technologies in this study, with a less-than-one adoption likelihood index. Consistent with the current adoption status, the technologies for monitoring animal GHG emissions ranked last in terms of potential for adoption. These results suggest that the potential PLF adoption in the near future is more likely to focus on technologies that assist in feed management and health monitoring, which would increase short-term farmers' profitability, rather than on environmental and climate change considerations, that may reduce long-term productivity through increasing heat stress, decreasing forage quality and availability, and more frequent extreme weather events.

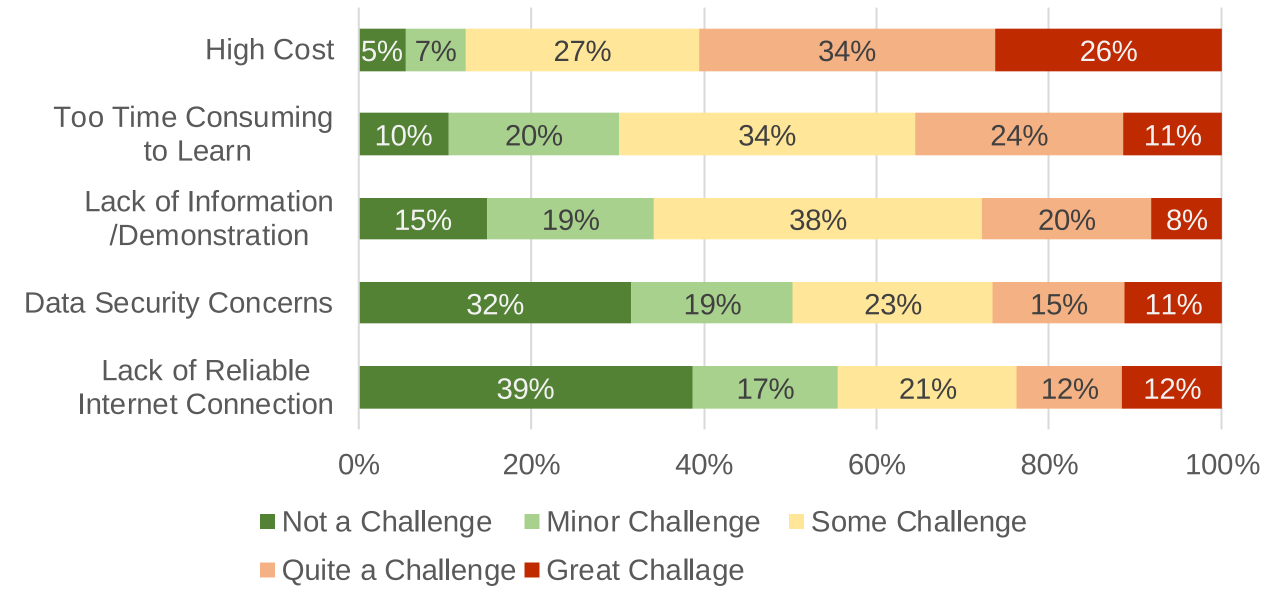
As PLF technologies continue to develop rapidly for commercial application, it is crucial to understand farmers' needs and interests. Our survey data shows that grazers are most interested in the precision technologies for forage monitoring and estimation (species composition, quality, and quantity), followed by precision mineral and forage supplementation. Hence, efforts should focus on developing and commercializing such categories of technologies. In contrast, environmental-oriented PLF technologies are less likely to be adopted by producers. External financial support should be provided to enhance the adoption rate of such technologies.

Challenges to PLF Technology Adoption

Despite the potential benefits of PLF technologies, our survey data indicates that respondents' adoption remains low. Our survey findings provide a better understanding of the potential reasons underlying these low adoption rates. Among all listed challenges, high cost is the most frequently cited as a great challenge by 26% of respondents, while 5% of respondents did not consider it a challenge (see Figure 2).

The time-consuming learning process of new technologies was perceived as a great challenge to PLF adoption by 11% of respondents, while only 10% did not think it was a challenge, indicating that 90% considered

Figure 2. Perception of Challenges in Adoption of Precision Grazing Technologies



Source: Authors' calculations.

it a challenge to some extent. Meanwhile, 8% of respondents found a lack of information or demonstrations a great challenge to adoption, whereas 15% did not perceive it as a challenge. A lack of validation and demonstration in realistic operating conditions can lead to a lack of trust from producers. Concerns regarding data security and unreliable internet connection were perceived as the least significant challenge, with 32% to 39% of respondents not considering them as barriers.

Additionally, Table 2 shows that older producers (69 years or older) are more likely to perceive the lack of information/demonstration, data security concerns, and lack of reliable internet connection as barriers to adoption. Older farmers were more likely to perceive the lack of information on crop precision technologies as a challenge (Wang, Jin, and Sieverding, 2023). However, the effect of age on PLF adoption decisions remains ambiguous (Paustian and Theuvsen, 2017; Lima et al., 2018), possibly because precision technologies require high investment and older producers are more likely to have fewer financial restrictions.

Our survey results indicate both financial and informational support could boost the adoption of precision technologies for grazing livestock management, especially those with the potential to provide positive environmental benefits. The financial payments or subsidies for PLF technologies are more limited compared to precision technologies for crop production. For instance, precision pesticide applications, variable rate fertilizer, and irrigation technologies are eligible for cost-share payments from the Environmental Quality Incentives Program. Meanwhile, outreach efforts can provide educational support on technology information and demonstrations of realistic operating systems, especially for farmers of advanced age.

Table 2. Differences in Perceived Challenges by Young and Old Producers

Challenges	Age			Grazing Size		
	Older (≥ 69)	Younger (< 69)	Diff.	Larger (≥ 1,370)	Smaller (< 1,370)	Diff.
High Cost	3.66	3.70	-0.04	3.72	3.68	0.05
Too Time Consuming to Learn	3.16	2.96	0.20	3.05	3.07	-0.02
Lack of Information/ Demonstration	3.04	2.70	0.34***	2.80	2.95	0.12
Data Security Concerns	2.73	2.39	0.34**	2.36	2.48	0.12
Lack of Reliable Internet Connection	2.65	2.19	0.46***	2.47	2.67	0.20

Note. The numbers indicate the mean score, ranging from 1 = not a challenge to 5 = Great Challenge). *** and ** indicate the 1% and 5% significance levels. The criteria of 69 years old and 1,370 acres of grazing land is the median of our respondents.

Concluding Remarks

Amidst increasing scale in beef cattle operations, PLF technologies can effectively support management decisions and improve animal welfare and environments. A survey of farmers and ranchers in North Dakota, South Dakota, and Texas shows that the adoption rates of precision grazing technologies are low, ranging from 0.7% to 18.8%, depending on the type and function of the technology. The highest PLF technologies adopted are for improving feed management, whereas the least adopted technology is for monitoring animal GHG emissions. Additionally, future adoption trends are likely to align with the current adoption pattern, which focuses on improving feed efficiency and productivity.

The major challenges to PLF adoption are high costs, lengthy learning process, and lack of information and demonstration. Outreach efforts could be made to provide information and technical support, and demonstration of the use of PLF technologies could increase the familiarity of non-adopters with the technologies and shorten the learning process. While informational support may play a primary role in promoting productivity-oriented technologies, financial assistance has a crucial role in incentivizing the adoption of environmental-oriented precision technologies.

For More Information

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About the Authors: Oranuch Wongpiyabovorn (owongpiyabovorn@missouri.edu) is Senior Research Associate with the Rural and Farm Finance Policy Center (RaFF) at the University of Missouri. Tong Wang (Tong.wang@sdstate.edu) is an Associate Professor and Extension Advanced Production Specialist with the Ness School of Management and Economics at South Dakota State University. Hector Menendez (hector.menendez@sdstate.edu) is an Assistant Research Professor/Extension Specialist-Livestock Grazing with the Department of Animal Science at South Dakota State University. Airish Lou Yago (airishlou.yago@jacks.sdstate.edu) is a Graduate Research Assistant with the Ness School of Management and Economics at South Dakota State University.

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